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The Effects of an Injury Prevention Program in an Aquatic Environment on Landing Technique

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The Effects of an Injury Prevention Program in an
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ABSRACT

The Effects of an Injury Prevention Program in an Aquatic Environment on Landing Technique

Samantha E. Scarneo, University of Connecticut

Context: Musculoskeletal and anterior cruciate ligament (ACL) injuries have accounted for a majority of sports and recreational related injuries and are of major concern to the physically active population. Injury prevention programs (IPP) have proven to improve landing technique, decreasing vertical ground reaction forces (VGRF) resulting in injury risk reduction. Injury prevention programs in an aquatic-based environment may potentially elicit the same improvements as land-based programs. **Objective:** To examine the effects of a six week aquatic-based IPP on Landing Error Scoring System scores and VGRF. **Design and Setting:** All participants completed an aquatic-based IPP three times a week for six weeks in the pool. **Participants:** Participants were females, 163 centimeters or taller, able to swim, no LE injuries, and were screened to have poor landing technique (LESS-RT of 4 or more). **Main Outcome Measures:** Pre- and Post- test procedures including measuring landing technique was measured using the Landing Error Scoring System and VGRF. Pre-test procedures were completed prior to program implementation. Post-test procedures were completed following completion of the program. Participants also completed an open-ended questionnaire to obtain qualitative date pertaining to factors to facilitate adherence and compliance. **Results:** We observed that the aquatic-based injury prevention program significantly reduced both LESS scores ($P=0.004$) and left ($P<0.001$) and right ($P<0.001$) peak vertical ground reaction forces. In addition, participants increased the time to peak VGRF for the left limb after completing the program ($P<0.001$). **Conclusions:** Results indicated the aquatic-based injury prevention program improved landing technique as evident by the LESS and VGRF.

Key Words: Injury prevention program, aquatic-based environment, vertical ground reaction forces, landing error scoring system, anterior cruciate ligament, ACL

Review of the Literature

Impact of Sports Injury

An estimated 6.8 million injuries occur during sport and recreational activity each year.[1] Of these 6.8 million injuries, a study by Conn et al. estimates 42% of them did not seek emergency care from a hospital's emergency room, indicating these injuries were seen by an orthopedic doctor, sports medicine doctor, or other health care professional.[1,2] This same study estimated that 10.7% of all injury related emergency room department visits were for sports related injuries.[1,3] In addition, recent data from injuries in North Carolina high school athletes suggest that the medical, human capital and total economic costs per year were $940,608, $4.2 million and, 13.7 million, respectively.[2] This translates into an estimated national expense of $9.9 million in medical costs, $44.7 million in human capital costs, and $144.6 million in comprehensive costs.[2] With health care costs on the rise, it is critical now more than ever that health-care professionals, along with patients, begin thinking of ways to decrease these costs by reducing injury rates because they are an economic burden and a public health issue.

Sports related injuries have also accounted for missed work time resulting in decreased man power, lost revenue for both the company and the individual, and possibly long term health complications, such as osteoarthritis. It is estimated that approximately 25% of working adults lost one or more work days due to the injury event.[1] In addition to work time loss, sports related injuries have also resulted in 20% of school children missing one or more school days due to their injury.[1] This extent of lost activity emphasizes the burden that sports and recreational injuries place on our society across age groups and our health care system.[1]

Anterior Cruciate Ligament

Anterior cruciate ligament (ACL) disruption injuries have accounted for a large amount of sports and recreational related injuries and are one of the most devastating musculoskeletal injuries. It is estimated that each year between 75,000 to over 250,000 individuals in the United States will suffer a new injury to the ACL.[4] Injury rates are estimated as high as 2.8 and 3.2 per 10,000 athlete exposures in women's collegiate basketball and soccer, respectively.[5] In addition, recent estimates suggest that approximately 3 million dollars are spent annually on medical care associated with ACL injuries in the United States.[4,6] These costs are in addition to loss of seasons of sports participation, decreased scholarship funding, lower academic performance, loss of time at work, long term disabilities, psychological impacts, socioeconomic impacts and a significantly increased risk of knee osteoarthritis.

ACL Reconstruction

ACL reconstructive surgery has come a long way since the year 2000. Approximately 90% of all ACL reconstruction patients achieve a successful surgical outcome in terms of impairment-based measures of knee function, and 85% achieve a successful outcome in terms of activity-based measures.[7] Despite these optimistic long-term measures, these patients are typically limited in their day to day activities, especially sports and recreational activities. The poor long-term prognosis which accompanies an ACL injury can result in diminished quality of life and inability to compete at levels prior to injury.

To an athlete, an ACL injury can be a career-threatening, if not a career-ending injury. A meta-analysis by Ardern et al.[7], discovered the return to any sports participation was 82%, and return to pre-injury level of sports participation was 63% in athletes following ACL reconstruction surgery. Rehabilitation time after ACL reconstructive surgery can range anywhere from 6 to 36 months. Arden et al. reported a mean time between surgery and resumption of sport of 7.3 months.[7] However, another study by Brophy et al.[8] discovered that the mean return to soccer timeframe is closer to 12 months following ACL reconstructive surgery. When looking at long-term follow-up studies, the aforementioned researchers also discovered only 35% of soccer players who underwent ACL reconstruction were still playing the sport.[8] Of those athletes who were still playing, only 46% were still playing at the same or higher level of play as before their injury.[8] As displayed by the evidence mentioned, ACL injuries result in a prolonged return to play time frame and decreased level of play, therefore injury prevention is critical.

Re-Injury Rates

Along with the devastation following an ACL injury, comes the risk of re-rupturing the ACL graft, or the opposite ACL, after the first reconstructive surgery. Paterno et al.[9] report that athletes who undergo an ACL reconstruction surgery were 15 times more likely to sustain an ACL injury than a subject with no history of an ACL injury.[9] Recent investigations have also reported a re-injury rate as high as 10% of individuals who tear their ACL experience a recurrent injury to either the ipsilateral or contralateral side.[10-12] Paterno et al.[9] discovered that ACL re-injuries are more prone to occur on the contralateral knee rather than the ipsilateral and females are 4 times more likely to sustain a second ACL injury when compared to males. Consequently, secondary ACL injury prevention is critical to ensure there is no risk of re-injury.

Due to the high re-injury rate, large health care costs, and long term prognosis for other associated orthopedic injuries, investigators have found an interest in what biomechanical and neuromuscular factors play a role in this greater risk of subsequent injury. Factors such as increased vertical ground reaction forces and loading rate on the uninvolved limb during landing have been found present following an ACL reconstruction.[13] Furthermore, an additional study by

Paterno et al.[14] evaluated the biomechanical and neuromuscular variables during the landing phase of a vertical jump. The findings of this study indicate that net hip rotation moment impulse, frontal plane knee range of motion during landing, asymmetries in sagittal plane knee moments at initial contact and postural stability are collectively a strong predictor of a second ACL injury following initial ACL reconstruction.[14] Because of the high incidence of injury and re-injury, research indicates injury prevention interventions to be part of the key to avoid repeat injuries and possibly the development of osteoarthritis.

Osteoarthritis

An estimated 10% of the American population is diagnosed with osteoarthritis (OA).[15,16] After an ACL injury, individuals have an increased risk of developing knee osteoarthritis within 10-15 years.[17-20] ACL insufficiency leads to changes in kinematics and biomechanics in the knee resulting in altered movement patterns and leaving individuals more susceptible to OA. [21-23] In addition to ACL injuries, meniscal injury, bone bruises, and a variety of other injuries can also lead to altered gait. Alterations in gait result in modifications in weight-bearing loads of the knee joint which may lead to degenerative changes. OA development in injured joints is caused by intra-articular pathogenic processes initiated at the time of the injury combined with these long term changes in dynamic joint loading.[24] Additional critical variables including sex, age, genetics, obesity, muscle strength, activity level and re-injury are also associated with outcome. Researchers have shown as much as 60%-90% increased chance of OA developing in patients after ACL surgery and the highest incidence in patients returning to sports.[25,26] Lohmander et al.[18,24] investigated female soccer players and found that 82% had radiographic signs of osteoarthritis, but that the procedure of ACL reconstruction did not have any significant influence on knee symptoms. A similar study by von Porat et al.,[20] reported that degenerative joint disease may be associated with the ACL procedure itself and not the injury. However, Hoffelner et. al.[27] investigated the prevalence of OA in ACL reconstructive patients. They found that there was no increased risk in the development of OA in the long-term after ACL replacement when compared with their contralateral knee. This finding could mean that an ACL disruption itself results in increased risk of OA and that ACL reconstruction does not increase the risk further. As seen by the preceding studies, the risk of OA in ACL injured patients needs further examination. There are conflicting results of the injury directly results in the onset of OA and how the correlation appears. An ACL injury increases an individual's risk of OA due to the altered biomechanics and kinematics of the knee over the long term.

Mechanism of Injury/Etiology

Recent research suggests that biomechanics and poor kinematics of the lower extremities are a major risk factor causing the high amount of ACL injuries. However, there is very limited research available on the definitive mechanism of injury of an anterior cruciate ligament rupture. A prospective study by Hewett et al.[28] found that in 205 athletes in the high-risk sports of soccer, basketball and volleyball, only nine of them had confirmed anterior cruciate ligament rupture. These athletes presented with 2.5 times greater knee abduction moments and 20% higher ground reaction forces. Furthermore, stance time was 16% shorter than those uninjured resulting in increased motion, force and moments occurred sooner. [28] The researchers also provide evidence that athletes with increased dynamic valgus and high abduction loads are at an increased risk of anterior cruciate ligament injury. Although the findings in this study have the possibility of suggesting the possible mechanism of injury, a sample size of only nine creates a gray area in this research section. However, the methods used in this study have been developed to monitor neuromuscular control of the knee joint and may help develop controlled, targeted intervention programs to correct these abnormalities.[28]

Although there is a paucity in the literature of the mechanism of injury for ACL injuries, several investigators have analyzed video of ACL injuries for the specific mechanism per that sport or event. Evidence shows that approximately 70% of all ACL injuries are the result of a non-contact mechanism of injury. This non-contact mechanism typically occurs as an individual is planting, cutting or performing a jump.[29-31] Two of the main injury mechanisms for ACL disruption injuries in team handball were a plant-and-cut movement along with a one-legged jump shot landing. Both of these mechanisms occurred with forceful valgus collapse along with the knee close to full extension combined with external or internal rotation of the tibia.[31] Further studies investigated the mechanism of injury in basketball players. These findings suggest that female players land with significantly less knee and hip flexion and have a 5.3 times higher relative risk of sustaining a valgus collapse when compared to their male counterparts.[32] Boden et al.[29,33] explored the position of the hip and ankle during noncontact ACL injuries. Upon conclusion of the study it was found that initial ground contact with flatfoot or hindfoot along with knee abduction and increased hip flexion may be risk factors for ACL injuries.[33] The findings in these areas suggest that preventative programs could be initiated to enhance knee control and focus on avoiding valgus motion.

Altered biomechanics and kinematics play a role in these non-contact mechanisms of injury resulting in anterior cruciate ligament disruption. The most provocative position which yields the greatest ACL load comes when there is anterior tibial shear, knee valgus, and tibial rotation.[34] Further, investigators have discovered that external tibial rotation (body rotating internally) reported a higher incidence of injury.[29] The position of no return means when the body is positioned this way, the ACL will be compromised in some way. This position is femoral internal rotation and adduction, quadriceps dominant, knee valgus, and the tibia in external rotation.[35] A study by Boden et al.[29] revealed that a fixed foot and deceleration are also important components present within an ACL injury.

Risk Factors

Non-Modifiable

Several risk factors have been identified as being present in individuals who tear their ACL as mentioned above. These risk factors can be non-modifiable or modifiable. Non-modifiable risk factors include sex, hormones, femoral notch width, age, eminence width, and generalized joint laxity. Additional non-modifiable risk factors can include playing surface and shoe ware. A study by Uhorchak et al.[36] reported 24 ACL tears in 859 West Point Cadets and prospectively looked at the commonalities amongst the injured with regards to non-modifiable risk factors. The findings from these studies suggest that an increased eminence width and size of the femoral notch and generalized joint laxity are among the most significant risk factors for noncontact ACL injury observed in men.[36] Women were identified with several factors including narrow femoral notch, greater than normal laxity and an increased BMI (a modifiable risk – factor).

Modifiable

Modifiable risk factors are able to be corrected (modified) to decrease the risk of injury to a patient. These factors include body mass index (BMI), strength, and movement biomechanics.

Body Weight Index

Body weight and body mass index (BMI) can be defined as either modifiable or non-modifiable. There is no conclusive evidence linking BMI to a genetic trait, in which case an individual would not be able to change his or her BMI based on heredity. In a study by Uhorchak et al.[36] investigators discovered significant main effects for ACL injury with respect to body weight and BMI as risk factors. It was discovered that females who had a BMI one standard deviation above the mean, were at a 3.5 times greater risk than that of women with a lower BMI.[36] The explanation of the link between BMI and noncontact ACL injuries is one to be speculated. One connection could arise between the BMI and principals of being less fit. Because of the often inverse relationship existing between BMI and physical fitness, a less fit person may lack a training history of intense physical activity prior to entrance into a physical environment (sport, military, etc.).[36] While fully developed motor programs may lead to increased neuromuscular control, it is hypothesized less fit individuals are not able to fully develop the motor programs necessary for the type and level of activity they were participating in.[37] Without fully developed motor programs, individuals could have increased risk factors off the bat with neuromuscular control problems and biomechanical errors.[36]

Strength

When an individual is walking, their body impacts the ground and the ground impacts the body back with 2 to 3 times the person's body mass. When the individual is running, cutting, jumping, pivoting, etc. the forces can be magnified multiple times. These forces will always be greater than the individual's body mass, but with increased strength and motor control, it is thought that individuals can react to the forces and reduce their risk of injury. For example, contraction of the quadriceps at 0-45° of knee flexion has shown to increase the strain on the ACL. This is because the quadriceps group is an antagonist of the ACL.[38] Schoemaker et al.[39] showed that the quadriceps force at 20-25° of knee flexion demonstrates the greatest amount of anterior tibial displacement. Other investigators reported the highest amount of anterior tibial displacement between 0-30° of knee flexion.[40,41] In addition, researchers discovered that eccentric contracting display higher forces than either concentric or isometric contractions by up to 50%.[42] Therefore, activities such as landing from a jump and deceleration require an eccentric force to resist further knee flexion.[29] When an athlete's hamstring complex is weak, the hamstrings cannot combat the strength of the quadriceps muscle group resulting in an eccentric force high enough to disrupt the integrity of the ACL. This is an example of a muscular imbalance risk factor that can be solved through strength training of specific muscle groups.

Movement Biomechanics

Over 70% of all patients who experience an ACL disruption have a non-contact mechanism of injury.[29,43] Furthermore, the rate of non-contact ACL injury is more than 3 times higher in adult females compared to their male counterparts.[44,45] Several investigators have found an increased risk of lower extremity injury associated with specific landing techniques from a jump.[46-51] A prospective cohort study reported that women who displayed increased knee valgus angle and increased external knee valgus movements during a drop-landing task were at greater risk for ACL injury.[28,52] Specific movement patterns are associated with injury because they are known to influence the load and deformational forces on ligaments, meniscus/cartilage, and bone.[29,34,38,46,53] Examples of these movement patterns are landing stiffly without absorbing the force, or landing with excessive medial knee displacement and/or increased knee/hip rotation.[18,54,55] Potential risk factors are present within the sagittal, frontal and transverse planes. These risk factors include decreased knee flexion, increased anterior tibial shear force, decreased hip internal rotation angle, and increased knee internal rotation angle during dynamic activities.[56-61] Lower extremity movement patterns influence the load and deformational forces on ligaments.[59,62-66] These movement patterns are important and modifiable factors that may influence the risk of ACL and other lower extremity injuries.

Sagittal Plane

Females who have sustained ACL injuries have also demonstrated a 10.5° less knee flexion angle at landing when compared to the non-injured individuals.[28] Knee flexion angle greatly influences the ACL loading. This is due to the quadriceps contractions at low knee flexion angles (0-30°) can generate significant anterior tibial shear forces that facilitate high levels of ACL loading.[30,38,67] Knee biomechanics are not the only confounder of ACL ruptures. The biomechanics of the ankle joint when landing from a jump are also involved when looking at the risk factors of an individual for an ACL tear. Boden et al.[33] demonstrated patients who experienced an ACL rupture showed landing with the hindfoot or with footflat upon initial contact. Participants in the study who had not ruptured their ACL landed on their forefoot. These athletes who landed on their hindfoot or foot flat also demonstrated significantly less plantar flexion when compared to the uninjured athletes.[33] The position of the foot and ankle reduces the ability of the gastrocnemius and soleus muscles to absorb the ground reaction forces. In addition, the amount of time the calf muscles have to absorb the GRF can also disrupt the integrity of the ACL. It was also shown in the study by Boden et al.[33] that athlete's with an ACL rupture reached flatfoot position 50% sooner when compared to non-injured athletes. This reveal's that this shorter time frame resulting in less time for the muscles of the calf to absorb GRF can increase the strain on the ACL thus leading to a rupture.

Patients who experience an ACL disruption have also presented with significantly higher hip flexion angles at initial contact. Because of this increased flexion, the torso of the body is placed posterior to the knee resulting in an increased hip flexion and knee extension torque to stabilize the torso when landing.[33] This increased torque relays to an increased strain on the ACL ligament thus leading towards injury.

Frontal Plane

One of the key predictors of ACL injury in females appears to be an increased valgus motion and valgus moments at the knee during the impact phase of jump-landing tasks.[28] Females who have sustained ACL injuries have demonstrated an 8.4° greater knee abduction angle at initial ground contact and 7.6° greater at maximum when compared to the non-injured knee.[28]

Transverse Plane

Numerous studies have reported higher ACL strains during tibial internal rotation.[34,68,69] Myer et al.[70] discovered high compressive or internal torsional loads can cause ACL damage without damage (or minimal damage) to other internal knee structures. However, Boden et al.[71] discovered a higher incidence of external tibial rotation as a common mechanism of injury. When tibial rotation and knee valgus are in combination with each other or with anterior tibial shear force, the amount of ACL load is greatly magnified.[34,62,66,72]

Beiser et al.[73] utilized motion analyses to investigate anticipated versus unanticipated cutting maneuvers affected external loads on the knee joint. The researchers identified flexion and extension moments at the knee were similar in both conditions. However, valgus/varus and internal/external rotation moments during unanticipated cutting tasks had up to twice the magnitude of moments as compared to anticipated maneuvers.[73]

Vertical Ground Reaction Force

Evidence has been identified to relate vertical ground reaction forces to having a significant influence on injury risk. Ground reaction forces (GRF) can differentiate high risk and low risk individuals. Large amounts of ACL deformation occur during the combined loading state of tibial rotation and knee valgus.[34,38] Due to this, lower-extremity rotation and knee valgus during cutting and jumping maneuvers are known to generate extreme loads within the ACL.[74-77] When abducted, valgus orientated, greater forces are placed on the lateral aspect rather than the medial aspect of the knee. This increases the compressive forces on the lateral aspect possibly resulting in greater rotation of the joint. These improper biomechanics of individuals when landing from a jump can result in higher ground reaction forces, which have been shown to have an association with increased lower extremity injury risk. These increased knee abduction angles have been directly correlated with peak vertical ground reaction force (GRF). Increased knee abduction and GRF were observed in ACL-injured participants but not in uninjured athletes.[28] The findings in the Hewett et. al[28] study demonstrate that athletes with an increased valgus motion and valgus moment at the knee joint during the impact phase of a jump-landing task are at an increased risk for ACL injury.

Landing Error Scoring System (LESS)

It is estimated that as high as 82% of all ACL tears are due to a non-contact mechanism relatable to poor biomechanics.[43] To identify these individuals at high risk for ACL injury it is necessary to have a standardized tool for detecting the presence of multiple high-risk movement patterns. The Landing Error Scoring System (LESS) is an inexpensive clinical assessment tool that identifies potentially high risk movement patterns during a jump-landing maneuver. The LESS incorporates a multiplanar biomechanical analysis assessment which is more comprehensive than the previous clinical assessments of poor jump-landing biomechanics.[59,60,78-80] This system is based on a 22 point scale that assesses lower extremity and trunk position at the point of initial contact with the ground, maximum flexion and overall fluidity and range of motion. A higher LESS indicates poor landing technique with a higher risk of injury, while a lower LESS score indicates good landing technique and a corresponding lower risk of injury. The LESS was tested on incoming freshmen in the United States Military Academies versus the gold standard, two motion analysis systems. The results of the study demonstrated that the LESS significantly distinguished between groups on a range of jump-landing biomechanics that have previously been shown to be related to ACL loading and injury mechanisms. The study also identified that woman who have a higher risk of ACL injury when compared to men when performing the same activities were more likely to score in the poor LESS score group.[44,52] This study showed that the LESS is a valid and reliable tool for the identification of subjects with landing errors in multiple planes.[22] The researchers showed good-to-excellent interrater and intrarater reliability for the LESS.[22] In addition, a study by Onate et al .[81] discovered the LESS showed excellent expert versus novice rater reliability and moderate to excellent idem validity in assessing a drop landing task.

The LESS assessment tool allows investigators to evaluate landing technique and biomechanics and identify areas of weakness in these individuals. Increased knee valgus, decreased plantar flexion, exaggerated internal or external tibia rotation, and hip flexion upon landing from a jump are all factors present when individuals have poor landing technique. Individuals deemed to have poor landing technique increase their risk of injury to the anterior cruciate ligament.[82] Fortunately, these factors can be positively influenced through interventions like injury prevention programs.[83,84]

Injury Prevention Program (IPP)

Due to the astronomical amount of injury occurrences and billions of dollars of ACL injury related costs in the United States each year, it is apparent that injury prevention is needed amongst our communities. Injury prevention programs have shown large benefits in decreasing injury risk factors specifically reducing injury risk to the ACL and other parts of the lower extremities.[29,35] Preventive exercise interventions that successfully alter movement patterns though decreasing knee valgus, minimizing rotation, and increasing knee flexion have tremendous potential to reduce the risk of ACL and lower-extremity injury during sport and recreational activities. These programs are believed to be effective in improving biomechanical and neuromuscular characteristics during functional tasks, such as movement patterns during jumping, landing and cutting maneuvers therefore resulting in decreased injury rates.[49,85-88]

Effects of IPP's Warm-ups on Injury Rates

Recent research on the effects injury prevention programs on injury rates have established that individuals who undergo an IPP demonstrate lower injury rates than in controlled individuals.[89-93] Specifically, in a study of 1435 athletes the overall ACL injury rate among intervention athletes was 1.7 times less than in control athletes.[89] Non-contact ACL injuries for individuals in the training program were 0.04 per 1000 athlete exposures and 0.14 injuries per 1000 athlete exposures in the control group. Furthermore, non-contact anterior cruciate ligament injury rate among intervention athletes was 3.3 times less than in control and no ACL injuries occurred in the intervention group versus 6 among control athletes.[89] Walden et al.[94] found similar results with an injury prevention program demonstrating a 64% reduction of injury rate of the ACL in the intervention group compared to a control group. The results of this study discovered the risk of ACL injuries in practice and the second half of the season are significantly reduced to any other environment or time point.[89]

An additional study by Mandelbaum et al.[90] implemented a sports-specific IPP intervention with female athletes and found an 88% decrease in ACL injury the first year and a

74% decrease in ACL injury in the second year of the program. This same study identified individuals who completed a neuromuscular training program demonstrated 0.05 ACL injuries per 1000 athlete exposures compared to .47 ACL injuries per 1000 athlete exposures in a control group.[90] An additional study by LaBella et al.[92] found a non-contact ACL injury rate of .03 injuries per 1000 athlete exposures compared to .217 injuries per 1000 athlete exposures. In summary, the implementation of an alternative warm-up program consisting of specific neuromuscular and proprioception training techniques have been evaluated to decrease the risk of injury. These injury prevention programs must involve both verbal and physical feedback in order to correct poor landing technique.

IPPs on Modifying Injury Risk Factors

The aim of IPPs are to reduce injury rates through positively modifying injury risk factors. Several studies have identified the effects of an IPP on different injury risk factors. For example, a study by Lim et al.[95] explored knee flexion angles, dynamic knee torque and quadriceps-to-hamstrings ratios in female high school basketball players. The results from this study found significant increases in hip abductor, hip extensor and knee flexor strength as well as a significant improvement in the quadriceps-to-hamstring ratio.[95] Furthermore, a study by Holm et al.[96] found an IPP to significantly improve dynamic balance which plays a key role in knee joint dynamic stability and landing stiffness.

Additionally, Chappell et al.[97] examined the use of the Kerlan-Jobe Orthopedic Clinic Modified Neuromuscular Training program on the effect of knee kinetics and kinematics during stop-jump and drop-jump landing tasks. Results from this study demonstrated that athletes presented with a decreased valgus moment during the stop-jump task and an increase in maximum knee flexion during drop-jump task. Similarly, DiStefano et. al.[30] found similar results following examination of athletes landing technique prior to and following an injury prevention program. A significant decrease in landing errors was seen after the IPP and athletes with higher scores at the beginning of the season showed the greatest amount of improvement.[30] Results from these studies indicate that neuromuscular training through injury prevention program warm-ups can positively modify risk factors for athletes.

IPPs on LESS Scores

One of the main evaluation tools on the effectiveness of IPPs is the Landing Error Scoring System, described previously. Injury prevention programs are aimed at correcting biomechanical risk factors for lower extremity injury and the LESS objectively measures these outcomes. A study by DiStefano et al.[30] found that following an injury prevention program, LESS scores improved. When evaluating 173 youth soccer players from 23 teams, the researchers found that the players with the greatest amount of movement errors experienced the most improvement. This finding establishes that a program designed to change specific movements may enhance the effectiveness in the at-risk population, or the highest baseline LESS scores, and thus this population should be targeted.[30]

Augmented Feedback

Feedback has been an integral part of the ACL injury prevention program. Several investigators have examined the use of augmented feedback and its effects on jump landing forces.[51,98,99] Verbal feedback refers to verbal cues from a program implementer to a subject or athlete instructing them to “land softly”, “knees over toes”, “ get your butt back”, “bend your knees and hips”, etc. These cues have been studied extensively by investigators who have found that subjects in the augmented feedback group have significantly reduced their peak ground reaction force.[82] In a single session, subjects can assimilate instructions on how to jump and land properly, resulting in lower vertical ground reaction forces.

Effects on Vertical GRF

Ground reaction forces during athletic tasks influence the magnitude of anterior tibial shear by affecting knee flexion/extension moments. There is strong evidence to indicate that vertical GRF can be reduced with proper instruction on jumping and landing technique through IPPs.[49,100,101] A systematic review of the literature by Padua et. al.[102] illustrated that with proper technique instruction and trained professional supervision and feedback, vertical GRF can be decreased significantly. Studies illustrate that IPPs are able to manipulate an increase in knee flexion therefore resulting in a decrease in vertical GRF. This review demonstrates moderate scientific evidence to prove that integrated programs of instruction and feedback, balance, plyometric, and strengthening can improve sagittal plane knee biomechanics leading to decreased vertical GRF.[102]

Components of the IPP

A systematic review of the published literature of exercise injury prevention programs to decrease ACL injury risk has demonstrated moderate evidence supporting the use of specialized programs to decrease this risk.[30,103] Injury prevention programs are designed to influence the motor control of lower extremity muscles. Motor learning theory indicates that learning a new skill (i.e. movement pattern) should be accompanied by relatively permanent changes in the performance of the task.[90] For example, it has been shown that preparatory adductor activity and adductor-to-abductor co-activation represent pre-programmed motor strategies learned during these prevention programs.[104]

The programs in this review included proprioception-balance exercises and/or plyometric-agility exercises. Proprioception-balance training programs are designed to improve coordination and balance by balancing on one leg, balancing on an unstable platform, balancing while tossing a ball, amongst a long list of other tasks. Plyometric-agility programs incorporate dynamic tasks such as cutting, pivoting, line jumping and additional similar tasks. A study by Pfile et al.[45] showed that a plyometric training program produced kinematic and kinetic changes at the knee joint only, whereas the core stability group demonstrated changes at both the hip and knee joints. In both cases, these programs are designed to improve neuromuscular and biomechanical tasks thus decreasing the risk of injury.

However, it seems the most successful ACL injury-prevention programs incorporate proprioception-balance, plyometric-agility, strength, flexibility and also provide verbal feedback to promote proper technique and injury risk awareness above performance.[30,103] These comprehensive programs have been shown to improve knee flexion, knee valgus and hip motion immediately following an exercise-based injury prevention program.

Compliance

One of the more difficult challenges facing injury prevention programs and rehabilitation in general is compliance with the prescribed treatment plan.[105] In most cases, athletes have difficulty buying into the injury prevention program and under comply, or fail to commit all together. Injury prevention programs have demonstrated success in the ability to positively modify risk factors and decrease ACL injury rates through adherence and compliance to daily warm-up programs. A study by Soligard et al.[106] found that athletes with the highest rate of compliance had the corresponding lowest rate of injury. However, this study also saw a drop in compliance rates as the season progressed. Studies have identified several factors causing coaches to have poor compliance of their team's athletes. The top three factors include programs being too time consuming, players finding the drills too difficult, and too many sets and repetitions for young players to complete.[106,107]

Researchers have also identified goal setting, imagery, relaxation, and self-talk as tools to aid in increased rehabilitation compliance and effectiveness.[108-110] Goal setting involves creating a "goal window" in order to involve the athlete in the process and to track their progress.[111]A second set of psychological skills useful in rehabilitation compliance is the use of relaxation. Through relaxation techniques, athletes can reduce pain, anxiety, and muscle tension. Relaxation techniques also provide the ability to control breathing allowing the athlete to gain control over the situation and aiding in pain relief efforts.[111,112]

An additional mental aspect of rehabilitation compliance is the use of imagery. Imagery involves picturing or re-creating an experience in the mind.[111] The ability to utilize imagery can be most beneficial in improving concentration during rehabilitation, leading to an increased effort during the exercise. A study done by Driediger et al.[113]found that if athletes are unable to participate in exercises due to their injury, mental imagery can be used to rehearse sport specific skills in their minds. Furthermore, the study indicated that the ability to utilize imagery had a profound effect on the athlete's rehabilitation plan and the athletes believed that the use of imagery was a critical aspect in rehabilitating their injury.[112] Additionally, imagery provides a positive outlook, ability to control stressors, improve self-confidence, ability to manage pain, and the ability to promote healing by imaging injured ligaments or bones repairing themselves. In injury prevention programs, athletes must use the verbal cues mentioned earlier (knees over toes, land softly, land shoulder width apart) along with imagery of these cues in order to aid in the effectiveness of the programs.

Duration

Injury prevention programs with successful outcomes, such as injury-rate reduction, improved neuromuscular and motor control or performance, are conducted 2-3 times per week for 4-6 weeks and last 10-15 minutes at a minimum.[19,89,90,99,114-118] Many effective IPPs can be completed in less than 20 minutes, however a duration of less than 15 minutes per session is necessary because these programs need to be feasible within a short practice time frames.[88,119] Recently, a group of researchers have created the Dynamic Integrated Movement Enhancement (DIME) program with the goal of developing a program of equal efficacy to proven injury prevention programs but with duration of less than 15 minutes.[30] This program focuses on balance, agility, and correct form when running, cutting and jumping and has been validated using a youth soccer population. Their findings demonstrate that both age groups tests improved their landing patterns following the completion of the DIME program based on an overall negative LESS total change score.[30] The data from this study validate that key markers of movement based risk factors can be modified using the DIME to reduce subsequent injury risk.

Retention

When evaluating motor skill learning, investigators often base their findings on retention tests when subjects are re-tested after a time of no longer performing the program. Researchers have identified an immediate (two minute) and delayed (1 week) performance testing reduction of ground reaction forces.[82] Although there have been immediate improvements in movement patterns following an exercise-based intervention program, it has been found that these programs have short-lasting effects and often athletes return to their pre-training levels within 1 year of discontinued training. There has been slim research in the field of long-term retention of movement-related changes. As previously stated, in a single session, subjects can assimilate instructions on how to jump and land properly, resulting in lower vertical ground reaction forces.[51,82,99,100] Another study by Padua et al.[86] compared the retention of improvement from a three month and a nine month injury prevention program. This study demonstrated that following the long-term nine month program and a three month detraining period, individuals demonstrated improved movement quality patterns, measured by the LESS test. The researchers found that three-month and nine-month injury prevention programs facilitate similar improvements in technique, but that only the nine-month intervention demonstrated retention of overall movement techniques in the total LESS score.[86]

These findings suggest that although acute alterations in movement control are present following an ACL injury prevention program, they do not necessarily translate into long-term retention of the biomechanical and neuromuscular changes.[86,100,120] Therefore in order to increase retention rates, we must lengthen the time of treatment, or the length of the IPP. There is the opportunity to increase the duration of program exposure for high risk individuals (patients after ACL reconstructions) in an aquatic environment.

Aquatic Based Exercise

One of the biggest uses of IPPs with regards to ACL injury comes in place following an individual's first ACL tear. As previously mentioned, the risk of re-injuring the ACL on the contra- or ipsi-lateral sides is very high and because a majority of ACL injuries occur due to poor biomechanics, this indicates that the individual or athlete must correct their movement patterns. Rehabilitation for ACL injuries on land can be prolonged and does not allow much jumping, landing, or cutting tasks in the first few months. These limitations dictate when the physical therapist or athletic trainer can begin training individuals on correct biomechanics and therefore limit the amount of time the injured individual can be working on their correct movement technique. However, aquatic-based exercise can be used as a tool for rehabilitation or injury prevention programs.

Assistive Properties of Water

The buoyancy property of water which allows for a decrease in body weight can be assistive, supportive or resistive depending upon body and limb position and motion.[121] Depending on the amount of the body that is immersed in the water will depend on the amount of body weight offloaded.

Additionally, increased cardiac output during immersion has shown to increase blood flow to the skin and muscles of the body resulting in an increase in oxygen availability.[122] Studies have identified resting muscle blood flow on land to be a baseline of 1.8 mL/min/100 g tissue and to increase to 4.1 mL/min/100 g tissue with immersion of the body to the neck. This increase in blood flow to the muscle results in a significantly increase duration of oxygen availability to the working muscles.[122]

The properties of water also allow for increased resistance. The viscosity and density of water compared to air offers an accommodating resistance, which increases as a square value when the movement in the water increases.[121,123,124] Additionally, viscous resistance increases as more force is exerted against it.[122] The resulting resistance can play a role in strength training and also provide dynamic stability to individuals improving balance and coordination.

Due to the body's density being slightly less than water (averaging a specific gravity of 0.974), the human body displaces a volume of water weighting slightly more than the body. Because of this, the body gets forced upward by a force equal to the volume of the water displaced, resulting in decreased joint force.[122]

Aquatic VGRF

Aquatic-based environments present with unique properties which allows for the opportunity for individuals to begin otherwise dangers tasks on land, earlier in the water, safely. When individuals are immersed in water, a percentage of their body weight is unloaded, resulting in the reduction of weight bearing impact.[125] Performing exercise in shallow water has been shown to reduce weight bearing impact by 70-75% of one's body weight but allows contact forces to occur, depending on the amount of the body that is submurged.[126] A study by Alberton et al.[127] in April 2013 found that underwater weight reduction at the xiphoid process depth demonstrates a 68.8% body weight reduction. However, research on specific aquatic fitness class type exercises have illustrated no differences in vertical ground reaction forces between exercises performed at shoulder or navel depths.

As previously mentioned, re-injury rates following an ACL reconstruction are high and early implementation of injury prevention programs play a key factor in decreasing the risk for re-injury. When ground reaction forces are increased, the risk of injury increases. However, studies done in an aquatic environment have shown changes in the magnitude following the shape of the force-time curve for vertical, anterior-posterior and medio-lateral ground reaction forces.[128,129] Exercises performed in the aquatic environment ranged from 48-63% reduction of GRF when compared to dry land exercises.[128,129] These findings contradict the findings of Miyoshi et al.[130] who found a reduction of approximately 30% of GRF when walking in water as compared to land. It is possible these findings suggest that different exercises in the water account for varying differences in GRF. Nonetheless, the results from the aforementioned studies demonstrate aquatic-based exercises decrease joint stress impact is reduced and therefore probable reduction in injury risk.

Aquatic Rehabilitation

The combination of all of the effects of water make aquatic based exercise an ideal environment for rehabilitation of most injuries. Several studies have identified aquatic exercise to provide advantages over standard land-based therapy for rapid return to athletics. For example, Kim et al.[131] identified elite athletes with acute ligament sprains in the lower limb to improve more rapidly in the aquatic-based group versus the land based group.

In addition to rehabilitation following an injury, aquatic-based exercise has also shown promising results in the improvement of performance in athletes. Martel et al.[132] studied the effects of an aquatic plyometric training on vertical jump in athletes. They found similar significant improvements in vertical jump in both land and aquatic groups after a six week program. However, the aquatic group experienced reduced muscle soreness with aquatic plyometric training resulting in a more promising option when compared to land based training.[132]

An aquatic-based injury prevention program can either coincide with or take the place of land based training either prior to a season as a prevention program or when injury does not allow for increased joint stress during a rehabilitation phase. Following an ACL reconstructive surgery, patients could implement an aquatic based injury prevention program which allows for earlier mobility. Injured individuals are able to perform more exercises earlier in the water than they would be able to on land. This allows for an increased treatment time along with an increased retention time which can reduce re-injury rates.

Conclusion

ACL injuries are one of the most devastating injuries to all individuals, specifically athletes. The rehabilitation time is long and tedious and most of the time the individual does not return to 100% of their pre-injured self. ACL injuries also lead to an increased risk of osteoarthritis which can be extremely painful and devastating later in life leading to total knee replacements. Fortunately research has proven the main cause for ACL disruption is due to poor lower body biomechanics and these factors can be influenced by injury prevention programs. However, there is paucity in the literature of the effects of an aquatic therapy intervention program on movement and landing technique. Therefore, the primary aim of this study is to examine whether there are any changes in LESS scoring and vertical ground reaction forces following an injury prevention warm-up in an aquatic-based environment. Any results demonstrating decreased LESS scoring and vertical ground reaction force following an injury prevention program will help to translate into greater use of such programs in rehabilitation and prevention resulting in a decrease in injury risk. A secondary aim of this study is to evaluate the attitude or perception of the aquatic based injury prevention program to our participants. Results from this research question will guide our ability to evaluate possible contributing factors to increase compliance of overall injury prevention program. The ability to begin these programs in an aquatic environment at an early phase in rehabilitation following an ACL reconstructive surgery can result in increased training periods followed by increased overall retention and improvements in movement patterns.

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Introduction

Despite the numerous health benefits from sports participation, it is estimated that 42% of all medical injuries result from sports and musculoskeletal and anterior cruciate ligament (ACL) injuries account for a majorities of these injuries.[1,2] It is also estimated that more than 38 million children and adolescents participate in sports each year in the United States and that one in three children who play a team sport is injured seriously enough to miss practice or games.[133,134] Additionally, recent evaluations suggest that approximately three billion dollars are spent annually on medical care, which are associated with ACL injuries in the United States.[4,6] To an athlete, an ACL injury can be a career-threatening, if not career-ending injury with poor long-term prognosis including increased risk of developing knee osteoarthritis, months of recovery, and high re-injury rates.[10-12,17-20]. Due to this high incidence of injury and re-injury along with the increase in health care costs, injury prevention interventions are the key to avoid repeat injuries and possibly the development of osteoarthritis.

Specific movement patterns during sport activity, such as landing from a jump, are associated with risk of lower extremity injury because they result in abnormal joint loading.[29,34,38,46,53] Examples of these movement patterns are landing with limited hip and knee flexion and poor force absorption, or landing with excessive medial knee displacement and/or increased knee/hip rotation.[18,54,55] In addition, sub optimal mechanics can result in higher ground reaction forces, which are associated with increased risk of lower extremity injury.[28,74-76] Therefore, risk of lower extremity injury may be increased in individuals with poor landing technique.[82] A cost effective method of evaluating landing technique is through the Landing Error Scoring System (LESS). This method allows for evaluators to asses landing technique using a variety of different factors which increase an individual's injury risk (i.e. increase knee valgus, decreased knee flexion, asymmetrical initial contact, etc). Landing techniques are, however, modifiable through exercise and instruction during injury prevention programs or rehabilitation.[83,84]

Land-based injury prevention programs improve landing technique[30], and reduce injury rates to the ACL and other parts of the lower extremities.[29,35] Successful programs utilize a combination of resistance, balance, plyometric and flexibility exercises to optimize movement patterns though decreasing knee valgus, minimizing rotation, and increasing knee and hip flexion during sport and recreational activities. These programs are believed to be effective in improving biomechanical and neuromuscular characteristics during functional tasks, such as movement patterns during jumping, landing and cutting maneuvers.[49,85-88] Conversely, compliance with these programs are poor with limited evidence as to why and how to increase adherence to the programs itself. Nonetheless, when an injured athlete is ready to begin rehabilitation for their lower extremity injury, use of a land-based program can induce high joint forces, is physically demanding and provides additional stressors to the lower extremity joints resulting in the possibility of further injury. However, recent evidence has shown a prolonged timeframe of learning and performing an injury prevention program can lead to increased retention rates.[135]

Aquatic-based exercise has been shown to be an effective and safe alternative to land-based exercise and may be a valuable tool for rehabilitation, conditioning or injury prevention programs.[131,132,136] When individuals are immersed in water, a percentage of their body weight is unloaded, resulting in the reduction of weight bearing impact.[125] Performing exercises in shallow water has been shown to reduce weight-bearing impact by 70-75% of one’s body weight but allows contact forces to occur.[126] As a result, joint stress impact is reduced and therefore could decrease the risk of injury and allow for earlier physical activity to be performed during injury rehabilitation. Furthermore, the buoyancy of water can be assistive, supportive or resistive depending upon body and limb position and motion.[121] The properties of water also allow for increased resistance. The viscosity and density of water compared to air offers an accommodating resistance, which increases as a square value when the movement in the water increases.[121,123,124] The combination of all of the properties of water allow for reduced injury risk and permit methods to begin rehabilitation earlier than they can on land. Therefore, the use of an aquatic-based environment may be an ideal way to introduce an injury prevention programs earlier into lower extremity rehabilitation, resulting in increased time dedicated to the program and possibly increasing retention rates. They may also be used as an alternative environment for injury prevention programs which could increase long term adherence.

The primary purpose of this study was to examine whether an aquatic-based injury prevention program can elicit changes in landing technique, as measured by the Landing Error Scoring System (LESS) and vertical ground reaction forces. Additionally, a secondary purpose was to identify what may attract or commit an individual to complete and injury prevention program. We hypothesize that the aquatic-based program will be effective with decreasing LESS scores and forces. This study may help to promote the use of injury prevention programs in rehabilitation and prevention efforts resulting in reduced injury rates.

Methods

Design Participants completed a screening test. Participants were asked to perform three repetitions of a standardized jump-landing tasks. The jump landing task required participants to jump forward from a 30-cm box a distance of half their body height, land in a target area, and jump for maximal height upon landing. A successful jump required participants to: (1) jump off of both feet from the box (2) jump forward, but not vertically, to reach the target area (3) land with both feet in the target area (4) complete the task in a fluid motion (see Figure a). Three members of the research team screened all participants using the Landing Error Scoring System Real-Time (LESS-RT) (See figure 7 in appendix) tool, which has been shown to be a reliable movement screening instrument.[86] The LESS-RT evaluates jump landing characteristics that have been associated with injury risk. Participants were included in the study if their score was greater than a four, indicating they had room to improve their landing technique. The first 15 participants that met these criteria were included in the training part of the study. Included participants performed the same jump-landing task for pre- and post- test procedures along with completing an open-ended questionnaire.

Figure a - Jump-Landing

Participants A sample of fifteen recreationally active college-aged females (n=15, age=20.6 ± 2.1, mass= 62.02 ± 8.18, height=164.74 ± 5.98) from the University of Connecticut volunteered to participate in this study. We estimated the sample size via a power analysis using previous studies which have demonstrated clinically significant differences (moderate effect) between individuals before and after completing an injury prevention program. An alpha level of significance = 0.05 and a desired power level of 0.8 were used for all analyses. All participants were between the ages of 18-25, recreationally active, 157 centimeters or taller to accommodate the water depth, and had no lower extremity limitations. All participants were able to swim and not afraid of water. Written informed consent was obtained from all participants. The university's Institutional Review Board approved this study prior to initiation of data collection.

Procedures

Movement Assessment

Participants completed two identical test sessions, before (PRE) and after (POST) completing a six-week intervention. Participants performed three trials of the standardized jump-landing task landing with each foot on a force plate (Model #4060-NC-2000, Bertec Corp., Columbus OH) during each test session. The jump-landing task was also videotaped using standard digital cameras (Canon FS400, Canon U.S.A. Inc., Lake Success, NY, USA) placed in front and to the side of the participants in order to capture frontal and sagittal plane images. The jump-landing test was graded at a later date from the videotapes using a valid and reliable clinical movement analysis tool called the Landing Error Scoring System (LESS) (Figure 8 in appendix).[44,52,81] The LESS is scored based on sixteen readily observable items of human movement during a jump-landing and uses a binary system to determine whether or not the participant demonstrated specific landing errors. A higher LESS score indicates poor technique in landing from a jump; a lower score indicates better technique.

Aquatic-Based Injury Prevention Program

Participants completed the 15-minute aquatic-based injury prevention program three times per week (based on participant schedules) for six weeks. This prevention program included a variety of balance, resistance, plyometric, flexibility, and agility exercises (See Figure 9 in appendix).[30,45,89,90,99,103,114-117] The aquatic-based injury prevention program was modified from land-based injury prevention programs that have been successful with reducing injury rates or improving landing technique.[30,45,89,90,99,103,114-117]

Open-Ended Questionnaire

Participants completed an open-ended questionnaire prior to and following the aquatic-based IPP. The questionnaire was developed by two researchers, one experienced. The before questionnaire included questions geared toward initial attractor, prior aquatic exercise history, and knowledge base on landing technique (see Figure 10 in appendix). The after questionnaire included questions geared toward overall experience, belief of change in landing technique and what our participants learned (see Figure 11 in appendix).

Statistical Analyses

A customized software program (MatLab 7, MathWorks, Natick, Massachusetts) determined the stance phase for each jump-landing task, which occurred between the time each participant made initial contact with the ground (VGRF>10N) and jumped for maximal height (VGRF<10N). Peak VGRF and the time to reach these forces (TIME) during the stance phase were calculated for each trial. An average value for LESS scores, VGRF, and the time to reach peak VGRF were calculated for both test sessions. Change scores were calculated for each dependent variable (VGRF, TIME, and LESS score) by subtracting the pre-test value from the post-test. Separate one-way between-subjects analysis of variance were performed for each dependent variable. All data was analyzed using SPSS (version 21.0, SPSS Inc., Chicago, Illinois) with an a priori alpha level of .05. Separation of 95% confidence intervals were used to evaluate significant differences between groups.

Qualitative data were evaluated using an open coding procedure[137] as a means to build an understanding related to IPP adherence and compliance. During the analysis of the open-ended questions, one researcher evaluated the data and identified concepts within the data that had fit (represented the topic of compliance/adherence) and relevance. Those key pieces of data were assigned codes, which represented the meaning of the data. A second researcher, who independently reviewed the data, reviewed the initial analysis to confirm the findings.

Results

All 15 participants completed both test sessions and the intervention program. We observed that the aquatic-based injury prevention program significantly reduced both LESS scores ($P=0.004$) and left ($P<0.001$) and right ($P<0.001$) peak vertical ground reaction forces. In addition, participants increased the time to peak VGRF for the left limb after completing the program ($P<0.001$).

Variable	Pre-Test	Post-Test	Change Score	95% CI of Change Score	Effect Size	P-Value
LESS (errors)	6.22 ± 1.68	4.5 ± 1.75	1.68 ± 1.68	(2.43, .93)	.96	<0.01
Left PVGRF (%BW)	2.67 ± .71	1.3 ± .46	1.31 ± .78	(1.74, .87)	-1.85	<0.01
Right PVGRF (%BW)	2.74 ± .85	1.42 ± .55	1.32 ± .78	(1.76, .89)	1.55	<0.01
Left TPVGRF (s)	.09 ± .03	.86 ± .28	-.76 ± .29	(-.60, -.93)	-2.75	<0.01
Right TPVGRF (s)	.94 ± .29	.86 ± .31	.08 ± .22	(.20, -.04)	.25	0.171

Table 1- LESS and VGRF

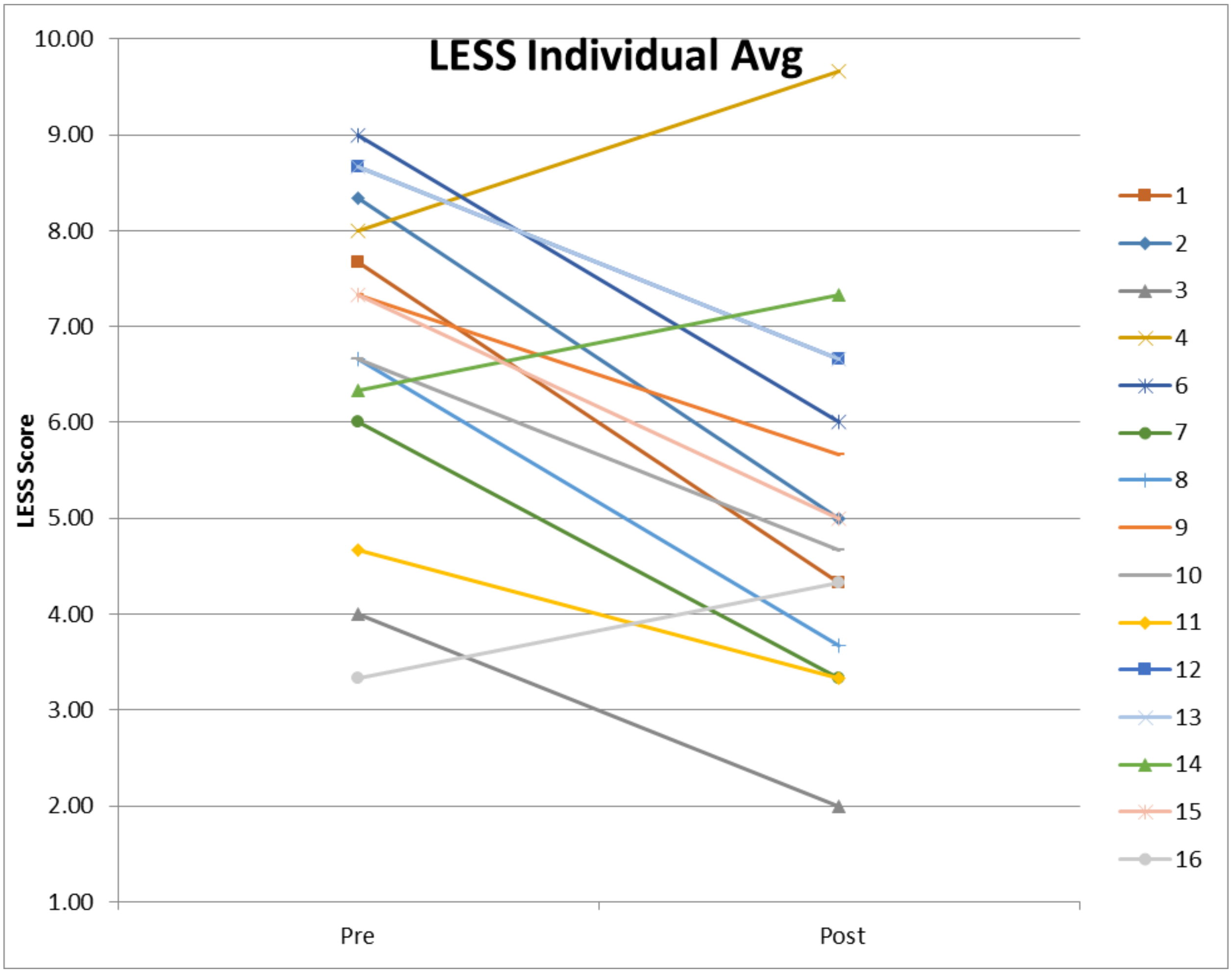


Figure 1- Individual LESS Avg Scores

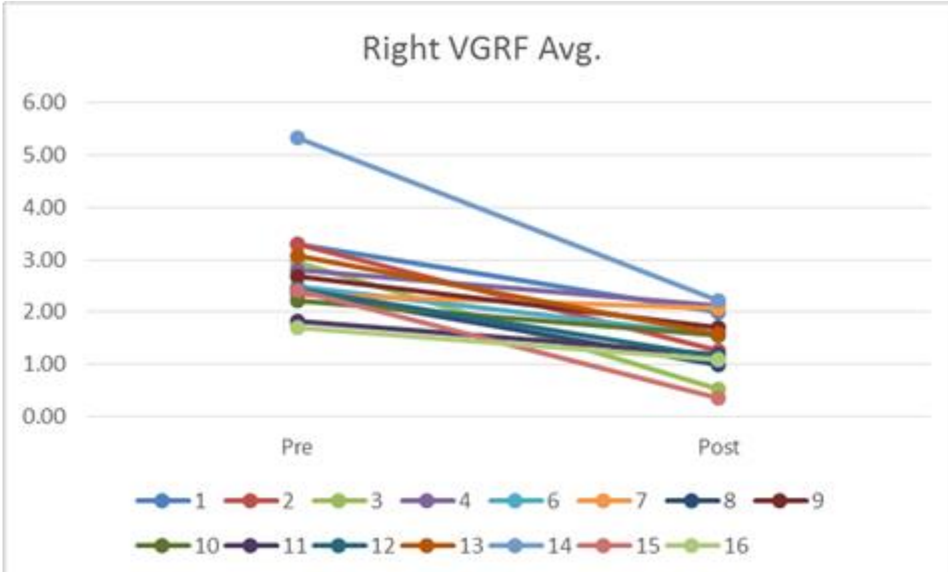


Figure 2- Individual VGRF Right Limb Avg

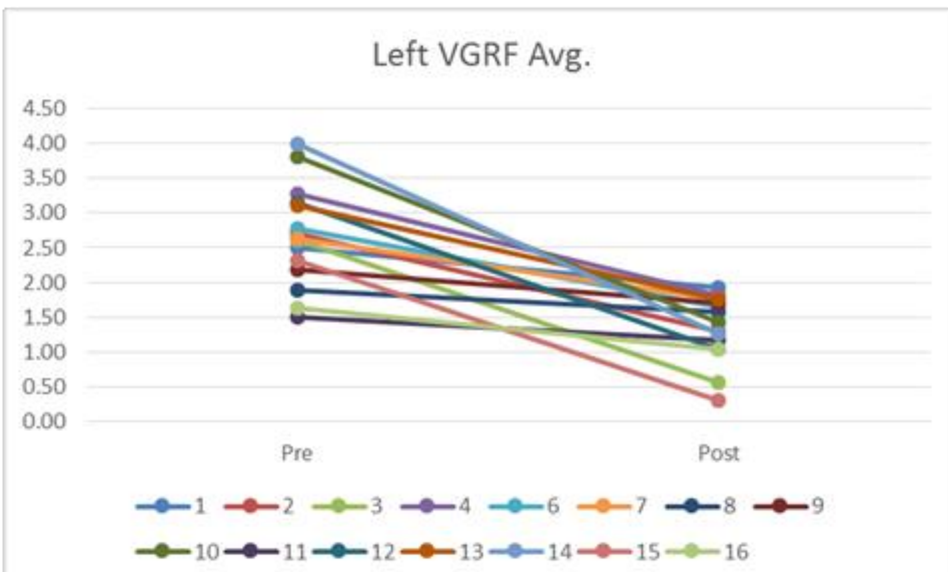


Figure 3- Individual VGRF Left Limb Avg

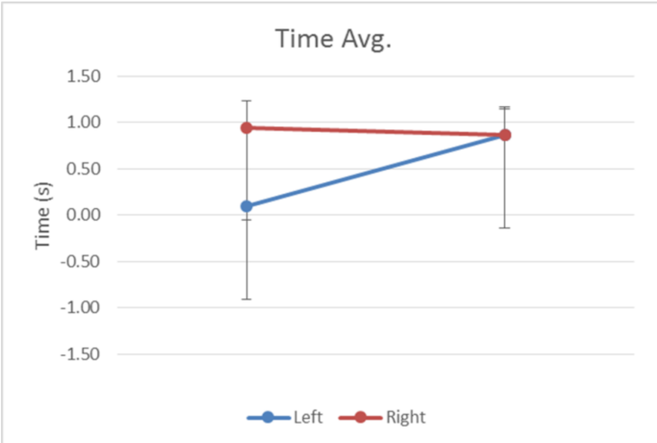


Figure 4- Time to Peak VGRF Average

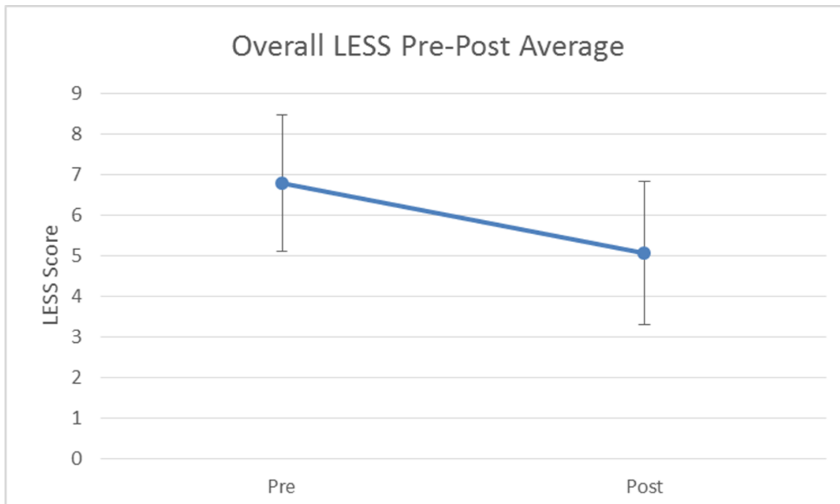


Figure 5- Average LESS

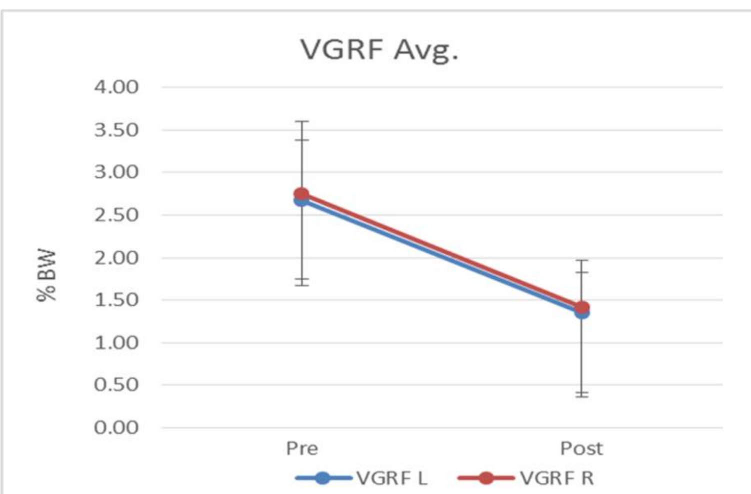


Figure 6-Average VGRF Left and Right Limb

Qualitative Approach Results

A factor, which was identified as a theme to facilitate compliance and adherence to the injury prevention program was *interest.* Participant #9 said “I wanted to gain information about landing technique…preventing further injury”. Participant #10 said they wanted to “learn about my landing technique”. Participant #1 said, “I was interested in participating in the aquatic study..”. Additionally, participants stated that the program was enjoyable or fun. Participant #1 said “It was fun!...doing it in a group made it more enjoyable”. Participant #11 said, “I really enjoyed being in this study.” Participant #12 said, “It was fun, I liked the social aspect.” Additionally, 100% of our participants believed their landing technique improved following the aquatic-based injury prevention program (See Table 2).

Subject	Pre-LESS	Post-LESS	LESS Decrease?	Quote
1	7.67	4.33	Yes	"Positively because I'm more aware of landing softly on my feet without my knees going into valgus"
2	8.33	5.00	Yes	"Yes I think my technique has positively changed…"
3	4.00	2.00	Yes	"I don't usually think about how I am landing & during this study, I did."
4	8.00	9.67	**No**	"I think it has changed positively"
6	9.00	6.00	Yes	"It improved!"
7	6.00	3.33	Yes	"Yes, positively. I am more aware of my landing & how I should land properly"
8	6.67	3.67	Yes	"Possibly, positively because I think about it more. Not sure if its permanent"
9	7.33	5.67	Yes	"I think so in a positive way. I am more conscious of proper landing technique."
10	6.67	4.67	Yes	"I believe my landing technique was positively changed throughout the exercises"
11	4.67	3.33	Yes	"I hope so…"
12	8.00	5.00	Yes	"I hope positively"
13	8.67	6.67	Yes	"I think it could…"
14	6.33	7.33	**No**	"I am not sure what my landing technique will necessarily be like. But I don't think they were in any way negatively changed."
15	7.33	5.00	Yes	"I believe it has improved because I felt better when I landed, like I actually knew the proper way to land."
16	3.33	4.33	**No**	"Yes, before I think I favored my right leg but now they are more equal."

Table 2- Participant identified belief of effects of injury prevention program on landing technique.

Discussion

The most important finding of this study is the use of an aquatic-based injury prevention program improved landing technique, as evident by decreased LESS scores and vertical ground reaction forces. These results agree with previous research demonstrating improved landing technique after the completion of land-based injury prevention programs[30,97] which have also been shown to reduce injury risk.[90,92,94] However, land-based programs may be physically demanding for some individuals, especially during rehabilitation following an injury. Performing injury prevention programs in an aquatic environment, which exposes an individual to lower external forces, [127,128,130] also appears to be an effective means of improving landing technique, and may reduce future injury risk.

Aquatic therapy has proven to be a viable and safe alternative environment for rehabilitation from lower extremity injury along with conditioning.[131,136] To our knowledge, this is the first study to examine the effects of a six-week injury prevention program conducted in an aquatic environment. The results of this study provide preliminary evidence that an aquatic-based program may be an option for individuals recovering from injury, and may not be able to perform a land-based injury prevention program, but requires further research. The aquatic-based injury prevention program may be an effective first step or alternative for individuals who need to improve their landing technique in a general female, recreationally active, non-injured population. Padua et al.[135] found the duration of an injury prevention program is positively related to the retention of landing technique improvements in youth athletes. The authors attributed this finding to overlearning, or the continued practice of a motor skill after achieving a high level of performance with the skill is necessary for retention. Exposing individuals to injury prevention programs which emphasize normal joint loading early in the rehabilitation process may allow for an increased duration of exposure and consequently improve long-term outcomes related to landing technique and re-injury risk.

Previous research has identified that the effects of a neuromuscular injury prevention program are dependent on the baseline level of participants, or room to improve.[30,138] Therefore, participants were included in our study if they scored greater than a four on the LESS-RT assessment tool indicating poor landing technique. Our results coincide with DiStefano et al.[30] which demonstrated significant improvement in LESS scores in individuals with a poor baseline performance on the jump-landing task.[30] These findings suggest that individuals with the most room to improve, and theoretically the greatest need to improve to reduce injury risk can improve as a result of this aquatic-based injury prevention program. While this study cannot directly compare the effects of the aquatic-based injury prevention program to a land-based program, the magnitude of improvements observed in LESS scores and VGRF appear to be equivalent or greater than previous research.[30,49,85,100,101]

High landing forces are associated with lower extremity injury risk.[28,46] Padua et al.[22] reported a positive relationship between poor landing technique observed by the LESS and landing and joint forces. Therefore, the reduction in landing forces we observed in this study appears to be related to the overall improvements in landing technique. Participants reduced VGRF by half after the aquatic-based injury prevention program, which is greater than previous literature utilizing land-based injury prevention programs.[51,100,101] Additionally, the participants increased the time to reach the peak VGRF after completing the program on one limb. Comparing the time to reach the peak VGRF between limbs during post suggests this increase unilaterally may be a result of participants landing more symmetrically (Figure 4). A study by Myer et al.[139] found increased lower extremity symmetry decreased injury rates following an

ACL reconstructive surgery. Our findings of symmetrical landing on both limbs coincide with this literature, in a non-injured population, assisting in supplementary reduction of injury risk following the aquatic-based injury prevention program. These findings support the evidence that VGRF can be reduced by proper landing technique instruction and feedback.

The aquatic-based IPP was generalized to the "high risk" population by providing feedback to correct multiple movement "errors", such as landing with limited flexion and excessive frontal or transverse plane motion. Previous research has identified various components of the LESS to have been modified greater than other components, such as knee rotation.[140] Participants in the present study presented with high baseline LESS scores, or poor landing technique, due to a variety of different errors (e.g. medial knee displacement, weight shift, limited sagittal plane motion). Analysis of the LESS independent components did not identify a single movement error to be primarily responsible for the overall improvement in landing technique. These generalized results indicate this program may be ideal for a universal college-aged recreationally active female population who are classified as "high-risk" and not specific to one single biomechanical error, such as landing with limited knee flexion alone. However, although we did see an overall decrease in LESS scores, there were no participants who fully corrected all of their errors from pre- to post- test. These errors could be addressed with continued participation in injury prevention efforts from either aquatic- or land-based programs.

Qualitative Findings

Although previous injury prevention studies have shown success with reducing injury rates and improving landing technique, adoption and compliance of these programs is poor.[141,142] Therefore, we evaluated the attractors to lead to increased adoption and compliance rates. An interesting finding from this study was that 100% of our participants believed that their landing technique changed in a positive aspect following the injury prevention program. Of the 15 participants, 12 demonstrated decreased LESS scores and improved landing technique. It is possible their positive attitude or positive perception towards their own landing technique assisted with the improvement in scores. The ability to have this positive attitude or perception may have led to increased confidence allowing for a greater adoption of this program. In addition, this finding can be associated with the use of imagery in rehabilitation programs and thus correlates with the findings of Prentice and Walsh.[109,110] Additionally, Martin et al.[108] discovered an applied model of mental imagery suggesting positive outcomes, such as confidence, are achievable through the use of sport-specific imagery in rehabilitation settings. The ability to positively imagine yourself improving your landing technique, may be an associated factor in explaining why our participants were able to attain positive results. However, the additional use of goal setting, positive self-talk, and relaxation may enhance compliance further. Additionally, our participants found our study to be enjoyable and fun. We sustained 100% compliance of our program with all 15 of our participants. Although our participants were compensated for their time, the results demonstrate that when an injury prevention program is performed in an enjoyable environment for the participant, they may be more likely to comply with the program in its entirety.

A limitation of previous research on the effectiveness of injury prevention programs is poor compliance and adherence to program.[106,107] Soligard et al.[106] found that athletes with the highest rate of compliance had the corresponding lowest rate of injury. The results from our study suggests that in order to improve adherence with an injury prevention program, both interest in preventing lower extremity injuries and being enjoyably must be present. While our participants had a variety of reasons for joining our study, the majority stated that one of their main reasons for participating in our study was because preventing injuries and learning about landing technique was interesting to them. Interestingly, it was observed only two participants cited an attractor to the study was that it was in an aquatic environment. This suggests that individuals are not attracted to this study because of the aquatic environment. Our participants all stated to be involved in athletics or physical activity in some aspect, therefore resulting in a desire to prevent injuries. While we acknowledge a vast difference between the physiological demands of recreationally active versus competitive college athlete's, we assume a translation between the two types of athlete's in their aspiration to prevent potentially season or career ending injuries.

Future Research & Limitations

This study was a preliminary study in evaluating the use of an aquatic-based injury prevention program on injury risk reduction. Without a pure control group, we acknowledge the results observed may have been influenced by a learning effect over time and we encourage further research to evaluate aquatic-based injury prevention programs. However, previous research demonstrates that LESS scores and VGRF are relatively stable over time, which suggests the current findings are likely a result from the program and not from a learning effect alone.[30,95,96] Since we only studied the program in a healthy population, we can only hypothesize that equivalent results are likely in an injured population. Future research should evaluate the effects of incorporating an aquatic-based injury prevention program into rehabilitation in a population of individuals after an injury.

Conclusion

Overall, our aquatic based injury prevention program demonstrated improvements in overall jump-landing technique and in vertical ground reaction forces. Female recreationally active individuals were able to perform an aquatic injury prevention program three times a week for six weeks, which may reduce their injury risk. These results are promising for individuals who are not able to perform land-based exercise injury prevention programs, but may want to start movement training early to encourage true motor learning. Motor learning is considered to occur when skills are effectively transferred to other tasks or environments, and retained over time. We are encouraged by these findings as participants in this study learned how to land appropriately in an aquatic environment and were able to transfer this learned technique to a land environment.

Appendix

Figure 7 – LESS RT

ID#: _______________ Date: ____________ Rater: ___________ Station: ______ □ Force Plate

<u>Landing Error Scoring System Real-Time: LESS-RT3</u>

<u>Frontal Plane View (2-3 Trials)</u>

		No Error	Errors		
1.	Stance Width:	□ Shoulder Width	□ Wide	□ Narrow	
2.	Maximum Foot Rotation Position:	□ Toes Forward		□ Toes ER > 30-deg	□ Toes IR > 30 deg
3.	Asymmetrical Foot Contact: Timing:	□ Symmetrical		□ Left	□ Right
				foot to contact ground first	
4.	Frontal Plane Shank Position at Initial Contact:	□ Vertical (over foot)	□ ABDucted (valgus)	□ ADDucted (varus)	
			knee medial to foot	knee lateral to foot	
5.	Frontal Plane Thigh Position at Initial Contact:	□ Vertical	□ ADDucted		
6.	Maximum Medial Knee Position:	□ None	□ > Medial Malleolus		
7.	Lateral Trunk Flexion:	□ Vertical	□ Left	□ Right	
				trunk laterally flexed to one side	
8.	Asymmetrical Loading / Pelvis:	□ Symmetrical	□ Left	□ Right	
		weight shifted OR pelvis side tilted down to one side more than other			

<u>Sagittal Plane View (2-3 Trials)</u>

9.	Ankle Plantar-Flexion Angle at Initial Contact:	□ Symmetrical		□ Left	□ Right
				foot to contact with heel first	
10.	Heel to Toe Landing	□ Toe to Heel Landing		□ Heel to Toe Landing	
11.	Knee Flexion Displacement:	□ > 45-deg	□ < 45-deg		
12.	Excessive Trunk /Hip Flexion Displacement:	□ Parallel with shank	□ > Parallel with shank		
13.	Total Sagittal Plane Displacement:	□ Soft	□ Average	□ Stiff (2)	
14.	Overall Impression:	□ Excellent	□ Average	□ Poor (2)	

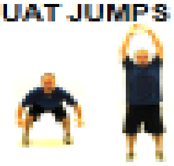
Total Number of Errors: _____________

Figure 8 – LESS (adapted from Padua et al.[44])

1. Knee Flexion at Initial Contact: *< 30 deg*	☐ No Error (0) ☐ Error (1)	
2. Hip Flexion at Initial Contact: *Hips are NOT flexed*	☐ No Error (0) ☐ Error (1)	☐ Left ☐ Right ☐ Both
3. Trunk Flexion at Initial Contact: *Trunk is NOT flexed*	☐ No Error (0) ☐ Error (1)	
4. Ankle Plantar Flexion at Initial Contact: *Land Heel to Toe (or) Flat Foot*	☐ No Error (0) ☐ Error (1)	☐ Left ☐ Right ☐ Both
5. Asymmetrical Foot Contact: *NOT Symmetric*	☐ No Error (0) ☐ Error (1)	
6. Asymmetrical Timing: *Feet do NOT land at the same time*	☐ No Error (0) ☐ Error (1)	☐ Left ☐ Right
7. Asymmetrical Heel-Toe/Toe-Heel: *one foot lands flat/heel-toe and the other foot lands toe-heel*	☐ No Error (0) ☐ Error (1)	☐ Left ☐ Right
8. Lateral Trunk Flexion at Initial Contact: *Trunk is NOT vertical*	☐ No Error (0) ☐ Error (1)	
9. Medial Knee Position at Initial Contact: *Knee medial to midfoot*	☐ No Error (0) ☐ Error (1)	☐ Left ☐ Right
10. Stance Width: *>shoulder width*	☐ No Error (0) ☐ Error (1)	
11. Stance Width: *<shoulder width*	☐ No Error (0) ☐ Error (1)	
12. Max IR Foot Position: *Toes > 30 deg IR*	☐ No Error (0) ☐ Error (1)	☐ Left ☐ Right ☐ Both
13. Max ER Foot Position: *Toes < 30 deg IR*	☐ No Error (0) ☐ Error (1)	☐ Left ☐ Right ☐ Both
14. Knee Flexion Displacement: *<an additional 45 deg of flexion after initial contact*	☐ No Error (0) ☐ Error (1)	
15. Hip Flexion Displacement: *Hips DO NOT flex more than at initial contact*	☐ No Error (0) ☐ Error (1)	
16. Trunk Flexion Displacement: *Trunk DOES NOT flex more than at initial contact*	☐ No Error (0) ☐ Error (1)	
17. EXCESSIVE Trunk Flexion Displacement: *Trunk flexion past parallel with lower leg*	☐ No Error (0) ☐ Error (1)	
18. Maximum Medial Knee Position: *> great toe*	☐ No Error (0) ☐ Error (1)	
19. Asymmetrical Loading: *A weight shift is present (1 side is loaded more than the other)*	☐ No Error (0) ☐ Error (1)	☐ Left ☐ Right
20. Wobble: In REAL-TIME: *Knee wobbles (demonstrates quick varus/valgus motion)*	☐ No Error (0) ☐ Error (1)	☐ Left ☐ Right ☐ Both
21. Joint Displacement: *Sagittal Plane*	☐ Soft (0) ☐ Average (1)	☐ Stiff (2)
22. Overall Impression	☐ Excellent (0) ☐ Average (1)	☐ Poor (2)

Figure 9 – Aquatic ACL Injury Prevention Program

AQUATIC ACL INJURY PREVENTION PROGRAM

Exercises	Description	Key Points
1. WALKING QUAD 10 each leg 	Hold heel of one leg as close to buttock as possible to feel stretch on front of thigh. Balance on other leg with knee slightly bent. Hold for 2 seconds.	Keep balance leg slightly bent Toes straight ahead
2. RUNNING BUTT KICKS 10 each leg 	Hands on hips. Step forward with one leg while keeping heel of other foot on ground. Feel stretch in back of lower leg.	Toes straight ahead Chest facing forward
3. STRAIGHT LEG MARCH 10 each leg 	Step forward and balance on one leg, raise your other leg straight ahead while keeping your knee straight.	Raise leg to lower height if needed to keep knee straight when lifting Toes straight ahead
4. CALF STRETCH 1 minute each leg	Stand close to the wall of the pool. Get in a lunge position. Bend your back leg slightly as you press your heel to the floor. Lean forward.	Lean far forward Keep your feet on the bottom of the pool
5. BACKWARDS HIP GATE	Walking backwards, open hips up and out.	Slowly Focus on stretch of adductors
7. Side Shuffle Each way 	Start with feet shoulder width apart and knees in a squatting position. Shuffle sideways 10 steps and repeat in the opposite direction.	Toes straight ahead Knees over toes
8. DOUBLE LEG TO SINGLE LEG SQUAT 5 cycles per leg	Feet shoulder width apart and squat down slowly as if you were sitting in a chair. Return to starting position. Perform next squat on single leg.	Straight as an arrow
9. SQUAT JUMPS 	Squat down, jump up for maximum height, land softly in squat position. Progress to single leg if possible.	Toes straight ahead Knees over your toes Sit back

Good technique and form are most important

Figure 9 continued

AQUATIC ACL INJURY PREVENTION PROGRAM

Exercises	Description	Key Points
14. FORWARD HOP TO BALANCE 5 each leg 	Hands on hips. Hop forward from one leg and land softly on opposite leg with trunk, hip, and knee flexed. Hold this position for three seconds. Begin landing on both legs and progress to one leg	Land as soft as possible Bend your knees, hips and trunk
10. SL WINDMILL **30 sec**	Start with balancing on one leg. Move arms in windmill side-to-side direction back and forth to create a current. Repeat on opposite side.	Knees over toes Bend your knees, hips, and trunk Balance
11. Z CUTS 	Run diagonally back and forth like a "Z". Make sharp cut while bending at the trunk, hips and knees.	Chest over knees Knees over toes Toes forward
12. SL Ball Toss 5 each leg 	Balance on one leg with knee slightly bent. Pass ball back and forth with partner while standing as still as possible.	Hold still like a tree
13. 180 Degree Jump And Hold 10	Hands on hips. Jump vertically and rotate 180 degrees. Hold this position for three seconds.	Straight as an arrow Land softly with trunk, hip, and knee flexed.
9. SL TWISTING HOP TO BALANCE 5 each leg 	Hands on hips. Hop off left leg and rotate clockwise 135 degrees. Hold this position for three seconds. Repeat on opposite side.	Land as soft as possible Land on right leg with trunk, hips, and knees flexed.
15. ICE SKATER 10 each way 	Right leg with knee bent, ready position. Hop sideways and land softly on the opposite foot, bending at hips, knees, and ankles. Hop immediately back to starting foot. Control the landing, maintain balance & stay low.	Hop and land softly Bend hips, knees & ankles Keep center of gravity low Knees over toes Explode back to other side
16. SL SIDEWAYS LINE HOPS 10 each leg	Hands on hips. Bounce side to side over line. Hop for quality (wk 1), speed (wk3), and height (wk 5)	Toes straight ahead Knees over toes

Always emphasize soft landings, knees over toes, & toes ahead

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